

Effect of team training on aircraft maintenance technicians: computer-based training versus instructor-based training

David C. Kraus^a, Anand K. Gramopadhye^{b,*}

^aGalaxy Scientific Corporation, Tucker, GA 30084, USA

^bCollege of Engineering and Science, Department of Industrial Engineering, Clemson University, Clemson, SC 29634-0920, USA

Received 1 December 1999; received in revised form 20 September 2000; accepted 4 October 2000

Abstract

The backbone of a safe and reliable air transportation system is the aircraft maintenance technician. These individuals work in a complex environment requiring above average teamwork skills as they coordinate, communicate and cooperate with other technicians and inspectors as well as with other departments within their organization. New technologies, such as multimedia computers, may be able to provide the necessary training to enhance their teamwork skills and improve their performance. To determine the effectiveness and applicability of computer-based multimedia team training for aircraft maintenance technicians, a controlled study was conducted to examine the transfer effects of computer-based team training (CBT) on team performance in the aircraft maintenance environment. To facilitate the research, a computer-based multimedia tool – the aircraft maintenance team training (AMTT) software – was developed. Results of this study indicate that computer-based team training was as effective as traditional instructor based team training.

Relevance to industry

Though the advantages of teamwork in the airline industry are widely recognized, it is not readily supported by work cultures. Providing teamwork skills will improve both performance and safety. Moreover, the importance of team training has also been emphasized in the national plan for aviation in human factors. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Aviation maintenance technician; Teamwork; Training; Multimedia; Transfer effects; Computer-based training; Aviation maintenance environment

1. Introduction

A sound aircraft maintenance system, one of the critical elements in ensuring a safe and reliable

transportation system (FAA, 1991), is a complex one with many interrelated human and machine components. The backbone of this system is the aircraft maintenance technician (AMT), who attends to the needs and requirements of maintaining an aircraft for a safe and operationally efficient flight. To ensure quality, federal aviation regulations (FARs), industry and federal policies, and approved corporate policies and procedures

*Corresponding author. Tel.: +1-864-656-5540; fax: +1-864-656-0795.

E-mail address: agramop@ces.clemson.edu (A.K. Gramopadhye).

specifically control the work performed on an aircraft. Unfortunately, though, maintenance and aircrew related aircraft accidents still occur (Johnson, 1997). Though 75% of aircraft accidents are classified as either pilot or human error, a recent study concluded that 18% of all accidents are maintenance related (Phillips, 1994). Recognizing this fact, the FAA, under the auspices of the national plan for aviation human factors, has pursued human factors research (FAA 1991, 1993), focusing in the maintenance arena on the AMT (e.g., Drury et al., 1990; Shepherd, 1992; Shepherd et al., 1995) to develop interventions to make the maintenance procedures, and hence the maintenance technicians, more reliable and/or more error free.

One facet of this issue, the development of the increased technical skills needed by modern AMTs, has been continually addressed by the FAA. For example, the Federal Government provides regulations concerning training on technical skills to assure that anyone working on an aircraft will meet certain minimum competency requirements. Specific regulations concerning training are given in Title 14 of the code of federal regulations (CFR). Part 147 of Title 14 specifies the curricula for the airframe and powerplant (A&P) schools, while Part 65 covers the certification requirements for mechanics and recurrent training. The FAA, through the Office of Aviation Medicine, has also funded efforts for the development of advanced training tools to train the AMTs of the future (FAA, 1991, 1993, 1995). These advanced tools include, for example, the Boeing 767 environmental control system tutor (ECS) and the multimedia system for training aviation regulations (STAR). It is anticipated that the application of these new training technologies will help reduce the gap between current AMT skills and those needed for the maintenance of advanced systems.

But as task analyses of aircraft inspection and maintenance activities (Drury et al., 1990; Taylor, 1990; FAA, 1991, 1993) have revealed, the complexity of the aircraft inspection and maintenance system is overwhelming, requiring above average coordination, communication and cooperation between inspectors, maintenance personnel, super-

visors and various other sub systems (planning, stores, and shop) to be effective and efficient. A large portion of inspector and maintenance technician work is accomplished through teamwork. In a typical maintenance environment, the inspector first looks for defects and reports them. Then, the maintenance personnel repair the reported defects and work with the original inspector or the buy-back inspector to ensure that the job meets pre-defined standards. During the entire process, the inspectors and maintenance technicians work with their colleagues from the same shift and the next shift as well as personnel from planning, stores, and other areas as part of a larger team to ensure that the task gets completed (FAA, 1991). Thus, in a typical maintenance environment, the technician is challenged to work autonomously but still be a team member, communicating and coordinating the activities with other technicians and inspectors.

Though the advantages of teamwork are widely recognized in the airline industry (Hackman, 1990), the work culture assigns responsibility for faulty work on individual AMTs rather than on the teams in which they work. The reasons for this could be the individual licensing process and personal liability, both of which often results in AMTs and their supervisors being less willing to share their knowledge and work across shifts with less experienced or less skilled colleagues. The problem is further compounded since the more experienced inspectors and mechanics are retiring and being replaced by a much younger and less experienced workforce.

Furthermore, the AMTs are not trained to work as team members. While the curriculum of the aircraft maintenance technology schools (AMTS) provide the necessary technical skills for students to receive both their airframe and power plant certificates (A&P License) as specified in the code of federal regulations (FAR Part 147, Appendix B), it currently does not address any instruction in teamwork skills. In fact, the current technical school environment encourages students to compete, and as a result, the AMTs are often ill-prepared for cooperative work. To prepare student AMTs for the workplace, new ways have to be found to build students' technological,

interpersonal and socio-technical competence by incorporating team training and communication skills into their curriculum. The importance of teams has been emphasized in the National Plan for Aviation in Human Factors (FAA, 1991, 1993; Shepherd, 1992) where both the aircraft industry and government groups agreed that additional research needs to be conducted to evaluate teamwork in the aircraft maintenance/inspection environment. Recent work has examined the effects of team training when applied to students at an Aircraft Maintenance Technology School. Using a previously designed framework, a pilot study conducted by Gramopadhye et al. (1996) found a positive correlation between team skills training and the improvement of team performance and overall task performance in an aircraft maintenance situation. In addition, the study concluded that student AMTs needed instruction in team skills to prepare them for the tasks found in the aircraft maintenance environment. The study, however, did not address the issue of the appropriate training delivery system, the method for presenting these skills training.

With computer-based technology becoming cheaper, the future will bring an increased application of advanced technology to training. Over the past decade, instructional technologists have provided numerous technology-based training devices with the promise of improved efficiency and effectiveness. Example of such technology includes computer simulation, interactive video discs and other derivatives of computer based applications (Johnson, 1990) and the media rich computer-based training software (system training for aviation regulations – STAR) for teaching federal aviation regulations (FARs) to A&P students (Chandler, 1996). Furthermore, multimedia has assisted in teaching difficult and complex skills (Gordon, 1994). Layton (1992) stated that the domain of aircraft maintenance is rapidly becoming the focus of computer-based training (CBT) aids. With the use of desktop computers with multimedia packages, new maintenance job aids have been developed to teach technical skills to maintenance technicians. AMTs may learn a variety of skills from CBT that range from scheduling preventive maintenance to apply-

ing expert systems for fault diagnosis and repair. Lufthansa Airlines believes so strongly in CBT that it has instituted computer-based training with video overlays to update the technical skills of maintenance technicians (Reichow, 1994). Because of the advantages offered, CBT may play a role in team training in the aircraft maintenance environment. It is important, therefore, to examine the effectiveness and applicability of computer-based multimedia team training for aircraft maintenance technicians. Since no one has yet examined this area, the general objective of this study was to understand the transfer effects of computer-based team training on team performance in the aircraft maintenance environment. To facilitate the study, a computer-based multimedia training tool – the aircraft maintenance team training (AMTT) software – was developed. The software program, which has been previously described in great detail (FAA, 1995; Kraus and Gramopadhye, 1999), was based on the instructional systems development (ISD) model (Leshin et al., 1992). During the development of the AMTT software, Kraus (1996) reviewed a number of training strategies in order to select a variety of training tactics that best fit the multimedia environment.

2. Background

In a controlled study, 36 subjects (aircraft maintenance technicians – AMTs) were assigned to two groups. These groups were designated as (1) Group IBT (instructor-based training) which received team training instruction through traditional instructor-based training, and (2) Group CBT (computer-based training) which received team training instruction through multimedia computer-based training in the form of the AMTT software. Every effort was made to maintain a constant curriculum and presentation sequence for both groups so that the only difference in the training between the two groups was the type of delivery system.

The study was divided into two phases: the instructional phase and the evaluation phase. In the instructional phase, the subjects received training on the four specific team skills – communication,

decision-making, interpersonal relationships, and leadership. In the evaluation phase, the effectiveness of the training was evaluated using objective and subjective measures as the teams performed two aircraft maintenance tasks on the hangar floor.

3. Methodology

Upon completion of the team training, the subjects in each group were randomly assigned to six three-member teams. After detailed discussions with instructors, mechanics, and training personnel at an A&P School (FAR, Part 147) and a certified domestic repair station (FAR, Part 145), each team was required to perform the following two tasks which were representative of normal aircraft maintenance.

1. Task 1 – routine maintenance task: determining the center of gravity of an aircraft and
2. Task 2 – non-routine maintenance task: trouble shooting an electrical problem on an aircraft.

The order in which the tasks were performed was counterbalanced within each group. The following section describes each task in detail.

3.1. Task 1 – routine maintenance (RM)

As part of the routine maintenance task, each team was to determine the center of gravity of a King Air 90A aircraft, a normal routine maintenance activity requiring a team effort to execute. To reflect a true maintenance environment, work cards providing general procedural instructions were supplied to the teams. For evaluation purposes, the routine maintenance task (Task 1) was subdivided into four major sub-tasks:

1. Sub-task 1.1 – towing,
2. Sub-task 1.2 – setup,
3. Sub-task 1.3 – weighing and calculating, and
4. Sub-task 1.4 – roll out.

Since weighing an aircraft to determine the center of gravity requires that the aircraft be located in a level and enclosed area, such as a hangar, with all doors and windows closed, the team's first task (Sub-task 1.1) was to tow the aircraft into the hangar. This task required that one person drive the towing tug while the other two team members walked at the wing tips to prevent accidental damage to the plane. This task was considered to start at the receipt of the work cards and was deemed finished when the aircraft was positioned and secured in the hangar.

The setup for weighing (Sub-task 1.2) which started the moment Sub-task 1.1 ended, required that the team first secure the platform scales from the storeroom, then position the scales in front of the landing gears, and finally roll the aircraft onto the scales. This procedure required one person to drive the towing tug, another to ride the brakes in the cockpit, and the third to monitor the movement of the aircraft in order to prevent accidental damage to the aircraft. Positioning the chocks fore and aft of the wheels, as well as riding the brakes was critical for the safety of the aircraft and the maintenance personnel during the setup procedure. This sub-task was considered complete when the brakes were set, the chocks were in place, and the tow bar was disconnected from the aircraft.

The weighing and calculating task (Sub-task 1.3) started at the conclusion of Sub-task 1.2. Once all the steps listed in the work cards were accomplished, the scales were read to obtain the weight of the aircraft. This task was considered complete when the team submitted their calculations to the evaluators.

Roll out (Sub-task 1.4) was the final task performed by the team. This sub-task, which started when the team initiated the reconnection of the tow bar to the aircraft, was deemed finished when the aircraft was moved completely off the scales and parked properly with the wheels chocked and the scales and miscellaneous equipment put away. As with the setup (Sub-task 1.2), this procedure required a team effort with one person driving the tug, a second person riding the brakes and a third person monitoring the aircraft's movement.

3.2. Task 2 – non-routine maintenance (NM)

The second task was a non-routine maintenance task involving trouble shooting an electrical problem. To assure consistency throughout the experiment, each team read a narrative from a simulated pilot's log describing a problem with the nose landing gear warning light. According to the pilot's log, on final approach to the airport, the nose landing gear warning light indicated that the nose landing gear was not down and locked when in fact it was. The team had to diagnose the problem, then identify/find and rectify it within a one-hour time period. This was an open-ended problem and, therefore, no guidance in the form of work cards was provided.

The overall non-routine maintenance task was subdivided into three separate but overlapping problems: (1) the circuit breaker for the landing gear lights had been placed in the "off" position, (2) a burned out bulb had been inserted into the landing gear light socket, and (3) the wire connecting the down and locked switch on the landing gear to the landing gear warning light had been disconnected. This third problem, which was not as obvious as the first two, necessitated the use of wiring diagrams located in the maintenance manual.

4. Data collection

As the teams performed the routine maintenance and non-routine maintenance tasks, their performance was evaluated using the three measures – self-evaluation, instructor's evaluation, and task performance evaluation – discussed in the following section.

4.1. Self-evaluation

Upon the completion of the RM and NM tasks, all subjects completed a questionnaire rating the performance of their teams on the application of the team skills of communication, decision-making, interpersonal relationships, and leadership. These were the team skills emphasized in an earlier FAA (1995) report on teamwork in the aircraft

maintenance environment. The self-evaluation consisted of a questionnaire with seven questions on each of the team skills with the subjects rating the teams on their application of each skill using a seven-point Likert scale.

4.2. Instructor's evaluation

Upon completion of both the routine and non-routine maintenance tasks, three independent evaluators completed a questionnaire identical to the subject's judging the teams on the application of the team skills. Fig. 1 gives sample questions used on the self-evaluation and instructor evaluation.

4.3. Task performance evaluation

As the teams performed the routine maintenance (RM) and non-routine maintenance (NM) tasks, the three evaluators independently monitored them and evaluated their performance in the categories of accuracy, safety, and speed. Table 1 provides a description of each of the performance measures.

5. Results

5.1. Effects of training delivery system on team skills perception

5.1.1. Self-evaluation

After completing both the routine and non-routine maintenance tasks, the subjects in groups IBT and CBT, scored their team on the application of the four team skills. A comparison of the scores for the two task types are shown in Fig. 2. With one exception, group CBT's use of communication skills, both groups scored the use of team skills higher on the non-routine maintenance task. Since this task was a problem-solving activity, it was unstructured, unlike the routine maintenance task which had work cards outlining step-by-step procedures. Thus, team members were required to use their functional understanding of the aircraft's electrical system as well as the technical data available in the maintenance manual. The

Sample Questions on Communication

1. Team members used proper terminology when communicating either verbally or in writing.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

2. Team members asked for clarification on a communication that was unclear.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

3. Team members called attention to a mistake made by another team member without being negative.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

Sample Questions on Decision Making

1. The team leader solicited input from team members.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

2. When discussing a problem, all team members participated in the discussion.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

3. Team members effectively used external sources of information to help make decisions.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

Sample Questions on Interpersonal Relationships

1. When asked for help, team members willingly and openly provided assistance.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

2. Team members had a positive attitude about their work.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

3. Team members encouraged and supported one another.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

Sample Questions on Leadership

1. The team leader accepted ideas and contributions from team members.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

2. The team leader fostered cooperation within the team.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

3. The team leader dealt effectively in inter-team cooperation / negotiation.

Very strongly disagree	1	2	3	4	5	6	7	Very strongly agree
------------------------	---	---	---	---	---	---	---	---------------------

Fig. 1. Sample questions from evaluator's/subject's questionnaire – communication.

Table 1

Description of performance measures used for routine and non-routine maintenance tasks

<i>Routine maintenance (RM) tasks</i>	
Accuracy	<ol style="list-style-type: none"> 1. Number of errors or number of times the team's procedure varied from the work card 2. Number of times an improper tool was used 3. Number of times that the equipment was handled incorrectly
Safety	<ol style="list-style-type: none"> 1. Number of times the safety of the aircraft was in jeopardy 2. Number of times the safety of an individual was in jeopardy
Speed	<ol style="list-style-type: none"> 1. Time to complete the sub-task (in min) 2. Percent of task completed within time constraint
<i>Non-routine maintenance (NM) tasks</i>	
Accuracy	<ol style="list-style-type: none"> 1. Was the problem diagnosed correctly? 2. Did the team locate the problem? 3. Did the team fix the problem?
Speed	<ol style="list-style-type: none"> 1. Time taken to diagnose the problem 2. Time taken to locate the problem 3. Time taken to fix the problem
Safety	<ol style="list-style-type: none"> 1. Number of times the safety of the aircraft was in jeopardy 2. Number of times the safety of the individual was in jeopardy

multi-layered problem in the NM task created a situation necessitating an iterative problem-solving process consisting of:

1. analysis of the current system state (e.g., Is the nose landing gear light illuminated?),
2. application of reasoning to diagnose the problem (e.g., there may be a lack power to the light or the light bulb may be burned out),
3. decision making (e.g., we have a consensus to check the light bulb first), and
4. use of feedback to determine the effectiveness of their decision (e.g., A new bulb has been installed, but it is still not illuminated).

All team members became involved in this process as the team diagnosed, located and repaired the problems. The higher self-evaluation scores on the non-routine tasks suggested that individual team members perceived an increase in the application of team skills during its performance. Thus, the application of team skills may be sensitive to task type. These results were similar to those reported by Taylor (1990) in their study of the effects of crew resource management training in maintenance.

The subjects indicated increased problem-solving abilities after receiving training on teamwork skills.

In summary, for self-evaluation, the scores on each team skill category were similar for both the groups for both the routine maintenance and the non-routine maintenance tasks, indicating that the effect of training delivery system on the teams' perception of their application of team skills is comparable. According to the team training model for the aircraft maintenance environment (Kraus et al., 1996), the task type (e.g., procedural, diagnostic or combination) is an external factor affecting team process over time. Comparable self-evaluation scores for the routine and non-routine maintenance tasks indicate that the subjects in both the groups were equally effective in applying the knowledge gained from team skills training to the two different types of tasks.

5.1.2. Instructor's evaluation

As each team completed the routine and non-routine maintenance tasks, the evaluators scored the members on their use of the four team skills.

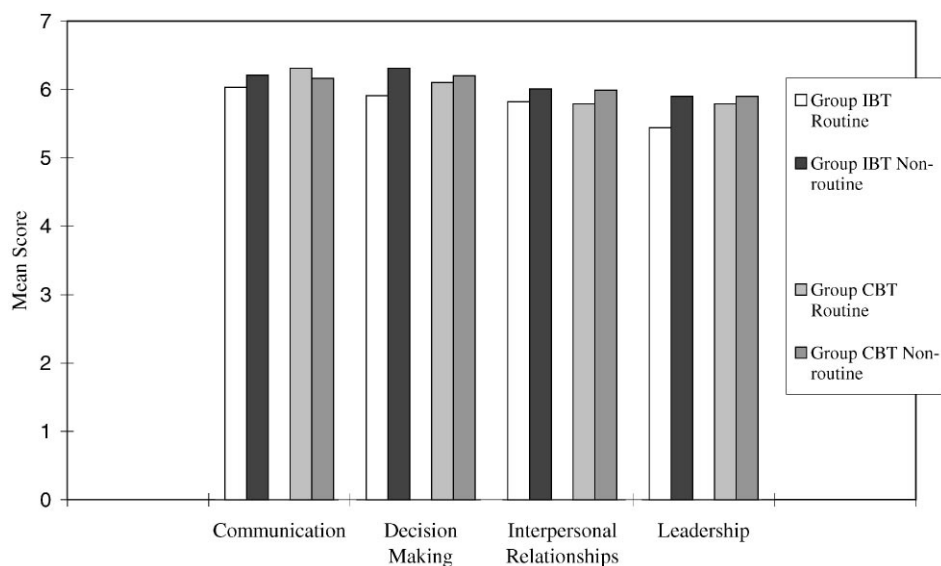


Fig. 2. Self-evaluation comparison of tasks (RM vs. NM) for groups IBT and CBT.

The results are provided in Fig. 3. The instructor's evaluation did not reveal any significant differences between the groups in each of the team skills categories. Thus, according to the evaluators' scores, the effect of training delivery system on subject's use of team skills in the performance of maintenance tasks, both routine and non-routine, were comparable.

The increase in use of team skills by teams in Group IBT during the non-routine task was also noted by the independent evaluators (Fig. 3). According to the evaluators' observation, however, the teams in group CBT had a decrease in the application of three team skills – decision-making, interpersonal relationships and leadership – during the non-routine task. This is in variance with what was reported by the team members in group CBT on the self-evaluation questionnaire.

Interestingly, for each skill category in the routine and non-routine maintenance tasks, the instructors were more conservative in their ratings than the subjects. A similar result was noted by Glickman et al. (1987) in a study examining the development of team skills over time. In their study, the instructors' ratings were consistently lower than the rating given by the team leader.

5.2. *Effects of team training delivery system on task performance*

As the teams performed the routine and non-routine maintenance tasks, the evaluators recorded the performance of the teams on accuracy, speed and safety violations. The following sections discuss these results.

5.2.1. *Accuracy*

The measure of accuracy for the routine task was the consolidation of (1) the number of errors made or the number of times the procedure followed by the team differed from the procedure specified in the work card, (2) the number of times an improper tool was used to perform a sub-task, and (3) the number of times equipment was handled incorrectly. Fig. 4 shows the number of errors made by groups IBT and CBT in performing the routine maintenance task. Although the total number of errors were the same for each group (10 each), the sub-tasks in which they occurred differed. For group IBT, the majority of errors occurred during Sub-tasks 1.1 and 1.2 (towing the aircraft and rolling the aircraft onto the scales), whereas for group CBT most of the

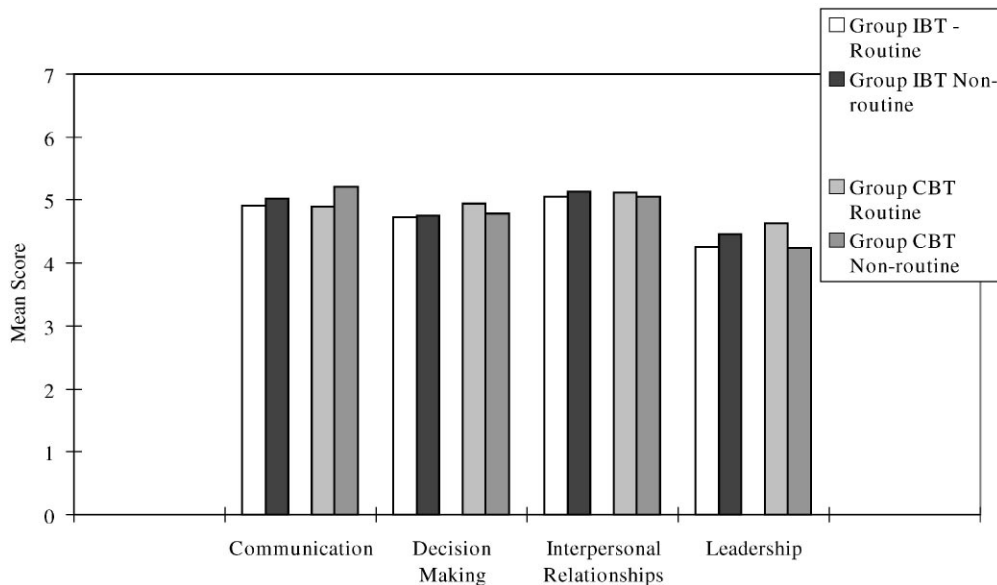


Fig. 3. Instructor's evaluation comparison of tasks (RM vs. NM) for groups IBT and CBT.

errors occurred for Sub-task 1.3 (weighing and calculating). The procedures for all three sub-tasks were provided in the work cards presented to the teams prior to beginning the task. Most of these incidents occurred because the team's procedures differed from those specified in the work cards.

Table 2 gives a breakdown of the typical errors made by the teams by sub-task. A review of the data reveals that the majority of the incidents were created by three teams in each group: for group IBT—T1, T3 and T5; group CBT—T8, T9 and T12. However, by averaging across the teams within a group, the number of incidents per team was low. Hence, statistically, there were no significant differences between the groups in performing the routine maintenance tasks.

It is interesting to note that the number of accuracy incidents for group IBT peaked during Sub-task 1.2 (roll up), whereas for group CBT the number of accuracy incidents peaked during Sub-task 1.3 (weighing and calculating) (Fig. 4). It can be hypothesized that teams were experiencing one or more of the four stages of team growth first identified by Tuckman (1965). In a review of 50 studies on team development, Tuckman noted that

the groups experienced four stages of growth: forming (a period of uncertainty characterized by the group members trying to determine their place in the group), Storming (a period of conflict where group members resist the influence of the group and rebel against the leader, the task or both), Norming (a period where in-group feelings and cohesiveness develop and new standards and roles are evolved), and Performing (a period wherein issues have been resolved, and the group becomes proficient in achieving its goals). In this study, most of the subjects knew one another (those from the overhaul facility having worked in the same company and students having taken classes together), but their assignment to the three-member teams was the first opportunity for them to work as a unit to accomplish specified tasks. As a result, the time taken in the forming stage was minimal. The peaks in accuracy incidents during Sub-tasks 1.2 and 1.3 were indicative of the storming stage. During these times, the team members tended to 'do their own thing', not following the procedures specified in the work cards, exemplifying resistance to the influence of the group and rebellion against the task. By the

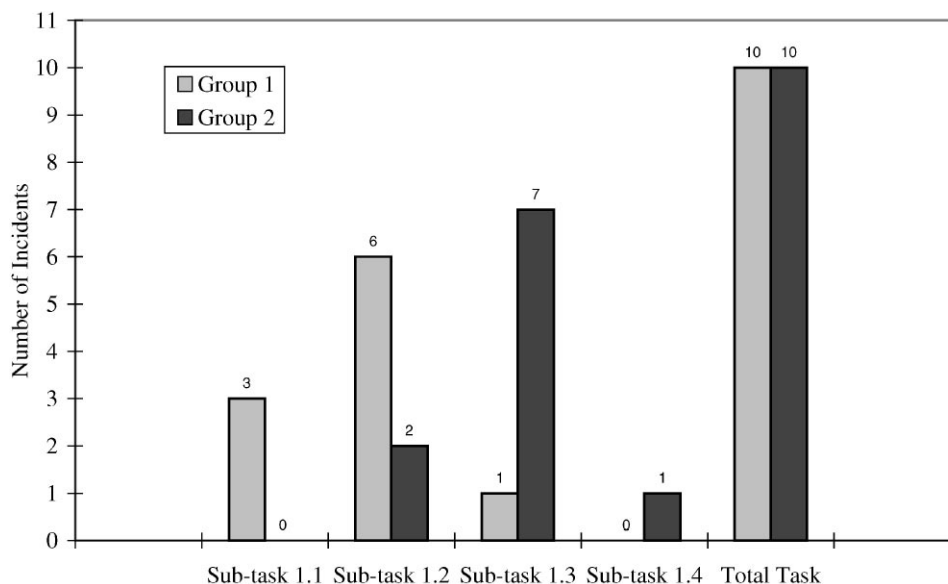


Fig. 4. Number of accuracy incidents for groups IBT and CBT during the routine maintenance task.

Table 2

Typical accuracy errors that occurred during the routine maintenance task

Sub-tasks	Typical errors that occurred
Sub-task 1.1 – towing	<ul style="list-style-type: none"> ● Failed to check oil and to drain toilet waste water system^a ● Failed to close hangar doors
Sub-task 1.2 – set up	<ul style="list-style-type: none"> ● Failed to place all control surfaces in neutral position ● Failed to close passenger door
Sub-task 1.3 – weighing and calculating	<ul style="list-style-type: none"> ● Failed to measure from the main wing spar ● Made incorrect measurement from the wheel center line to reference datum
Sub-task 1.4 – roll out	<ul style="list-style-type: none"> ● Failed to properly place chocks ● Failed to return scales to storage

^a There was no toilet waste in the aircraft, but the teams were required to check the waste water system.

fourth sub-task, the teams in both the groups seemed to be working well together. The number of accuracy incidents had decreased, and the teams seemed to have grown into the performing stage when group energy channeled towards the accomplishment of the task.

Since half the teams in both groups performed the routine maintenance task first and the other

half performed the non-routine maintenance task first, it may be argued that half the teams, those performing the non-routine maintenance first, should have grown past the storming stage prior to the routine maintenance task. There are two possible explanations why this may not be true. First, the stages of team growth are not time dependent (Tuckman, 1965). Some teams will pass

through a growth stage faster than others. Also, as noted by Wheelan (1994), some teams may get stuck in a stage or even regress to a previous stage. The teams in this study that started with the non-routine task may not have arrived at the storming stage until the routine task. Or they may have started their storming stage during the non-routine task and carried it forward to the routine task. Second, the team organization changed because a new team leader was typically selected. The new team organization coupled with a new and totally different task may have caused the team members to regress to an earlier stage, moving from a performing stage back to a storming stage, as they faced a new situation with new leadership.

Accuracy for the non-routine maintenance task was measured by whether or not the teams correctly diagnosed the problem (yes or no), located the problem (yes or no) and fixed the problem (yes or no). All 12 teams diagnosed, located and fixed Problems 1 and 2. Only two teams, T1 and T6, could not locate and fix Problem 3 within the allocated time. Statistically there were no significant differences between the groups; thus, the type training delivery system had no affect on the accuracy measures for the teams performing non-routine maintenance tasks.

The correlation analysis showed a positive correlation between the total average of post-training scores a subject received on all four team skills and the time it took to complete the routine maintenance task ($r = 0.4683$, $p < 0.004$). This would indicate that the subjects were applying the team skills knowledge they had acquired in order to finish the task in a timely manner. A positive correlation was observed between the accuracy measure for routine maintenance and the instructors' evaluation of the teams on the use of communication skills during the routine maintenance task ($r = 0.4322$, $p < 0.0085$), instructor's evaluation on the use of decision-making skills during the routine maintenance task ($r = 0.3411$, $p < 0.0418$), and self-evaluation of interpersonal relationships skills ($r = 0.4661$, $p < 0.0042$). These findings are consistent with other studies on the effects of communication and decision-making on team performance. In a study of the team evolution and maturation model, Morgan, Salas

and Glickman (1994) found that as the team's performance improves, the perception of the team members concerning communication and coordination increases. Also, in a study investigating whether teamwork process measures are associated with outcome measure, Brannick et al. (1995) found that team effectiveness was positively associated with decision-making and communication skills.

An obvious revelation after analyzing the accuracy scores for the routine maintenance and non-routine maintenance tasks was the overall low number of errors for both groups. The high-accuracy scores achieved by the teams can probably be explained within the speed accuracy tradeoff (SATO) context (Drury and Gramopadhye, 1991). Training delivered at A&P schools and through various training departments focuses on accuracy, emphasizing the need to minimize errors since these can be catastrophic (e.g., the case of a continental commuter airlines, the Continental Express, that flew without the tail de-icing boot properly attached, or the United DC-10 whose engine failed, severing control hydraulic lines and causing a crash at Sioux City). This perception of accuracy obviously seemed to transfer to the performance of the teams for both the RM and NM tasks.

5.2.2. *Safety*

Both the groups had almost the same number of safety violations for the routine and non-routine maintenance tasks. Table 3 provides a list of typical safety violations that occurred during both tasks. The safety violations were noted by the evaluators whenever they observed that either the aircraft's or an individual's safety was jeopardized. Fig. 5 indicates that the majority of the safety problems occurred in the routine maintenance task for Sub-task 1.2 when the plane was rolled up onto the scales. This is a critical time in the routine maintenance task. If the aircraft wheels are not chocked correctly and the parking brakes not properly set, the aircraft could roll off the scales causing serious injuries and damage. In fact, such an incident did occur during the performance of the routine task for Team T12. The team failed to properly set the parking brakes after rolling the

Table 3
Typical safety violations that occurred during the routine and non-routine maintenance tasks

Tasks	Typical safety violations
<i>Routine maintenance tasks:</i>	
Sub-task 1.1 (towing)	<ul style="list-style-type: none">● Removed wheel chocks prior to connecting towing tug● Failed to walk with the aircraft while towing it to the hangar
Sub-task 1.2 (roll up)	<ul style="list-style-type: none">● Failed to place chocks fore and aft of the scales● Failed to properly set parking brakes
Sub-task 1.3 (weighing and calculating)	<ul style="list-style-type: none">● No safety violations
Sub-task 1.4 (roll out)	<ul style="list-style-type: none">● No safety violations
<i>Non-routine maintenance tasks:</i>	
Problem 1 (circuit breaker)	<ul style="list-style-type: none">● No safety violations
Problem 2 (burned out bulb)	<ul style="list-style-type: none">● No safety violations
Problem 3 (disconnected wire)	<ul style="list-style-type: none">● Caused damage to junction box
	<ul style="list-style-type: none">● Replaced wire without first checking wiring diagram in the maintenance manual

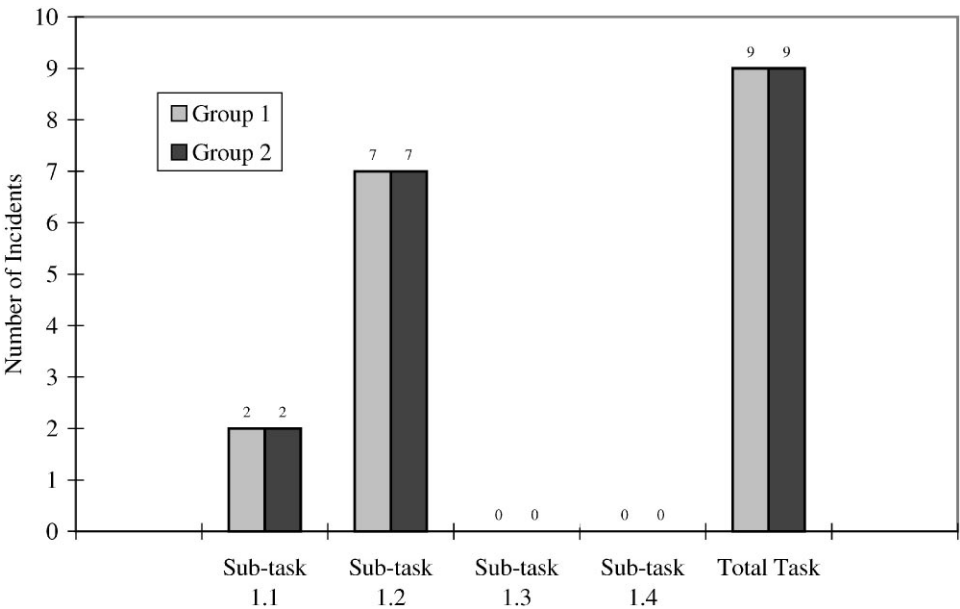


Fig. 5. Number of safety incidents for groups IBT and CBT during the routine maintenance task.

aircraft onto the platform scales, and during the weighing, the aircraft rolled off the scales towards the rear of the hanger. Fortunately, the chocks were properly placed stopping the aircraft and

preventing damage to the aircraft, the hanger, and the personnel. Interestingly, the above incident is typical of anecdotal evidence that describes similar horror stories wherein wide-body aircraft have

rolled out of the aircraft hangar, causing severe damage, both to life and property. Correlation analysis of safety scores and instructor's evaluation of the teams revealed that teams which displayed higher communication, decision-making, interpersonal relationship, and leadership skills had fewer safety violations on the routine maintenance task ($r = -0.5702$, $p < 0.0003$; $r = -0.8062$, $p < 0.0001$; $r = -0.5312$, $p < 0.0009$; $r = -0.4179$, $p < 0.0112$, respectively).

Statistically, the measurements on safety violations did not show a significant difference between groups for the non-routine maintenance task. Group IBT had one safety violation while Group CBT had four. Although Group CBT had a greater number of safety problems, a review of the data shows that the majority of the incidents were produced by one team, T11. In fact, they were caused by one person of that team. This individual, in his haste to locate the third problem, caused damage to the aircraft and injury to himself in three separate events. Excluding this one individual, we can conclude that the team training delivery system had no effect on the safety performance of the teams as they performed the non-routine maintenance task.

The lack of safety violations during the non-routine maintenance task could possibly be an artifact of the task. The NM task was essentially a problem solving one. Thus, it was more of a cognitive task unlike the routine maintenance task which was a highly procedural and manual, involving movement of the aircraft into the hangar, positioning the aircraft, and rolling the aircraft onto and off of the scales. Hence, the opportunities for safety violations were much less for the NM task than for the RM.

The overall number of safety violations for both the RM and NM tasks was much lower than those typically reported in the "real world" aircraft maintenance environment (Phillips, 1994; Rankin and Allen, 1996). The existing study was performed in a clean and quiet training hangar environment. There were no other AMTs working on the aircraft at the same time, thereby minimizing work interruptions and workflow. On an actual hangar floor, there are multiple skill groups such as avionics, hydraulics, maintenance, among

others, with multiple crews working on a single aircraft. It is a highly complex and dynamic environment wherein an individual AMT must not only work with his own team members but must also communicate and coordinate with other crews, supervisors, and inspectors. Thus, the work of a team is not only dependent on the intra-team factors but also on inter-team factors. In addition, there are other factors present in the "real world" but missing in the current study that could possibly contribute to the number of safety violations: environmental factors (e.g., noise, lighting); organizational factors (e.g., gate pressure, late night shift); subject factors (e.g., part-time workers, shift workers). Hence, we should be extremely careful before we draw any generalizations on the safety violations found in the current study.

5.2.3. Speed

The results of the statistical tests did not reveal any significant differences between the two groups on overall task completion times for the routine and non-routine maintenance tasks. Analyzing the performance of the groups on the routine maintenance task clearly indicated that there was a large variability in the performance of teams for the task as a whole (for group IBT, $SD = 32.4$; for group CBT, $SD = 24.5$), and for each individual sub-task (Sub-task 1.1: for group IBT, $SD = 9.72$; for group CBT, $SD = 18.3$, Sub-task 1.2: for group IBT, $SD = 27.6$, for group CBT, $SD = 12.9$, Sub-task 1.3: for group IBT, $SD = 30.2$; for group CBT, $SD = 31.1$, Sub-task 1.4: for group IBT, $SD = 3.2$; for group CBT, $SD = 0.5$). The teams expended over half their allotted time in the performance of Sub-task 1.3 (weighing and calculating) (Fig. 6). This was due to the fact that only a rough outline of the calculation procedures was provided in the work cards. More detailed step-by-step procedures were located in the manuals for the aircraft. A common complaint heard from the Lockheed subjects was, "We don't have to do this calculation at work. We just put the weights into the computer, and it calculates it for us." Leadership played an important role during this sub-task as evidenced by the fact that most teams tended to flounder not understanding how to calculate the

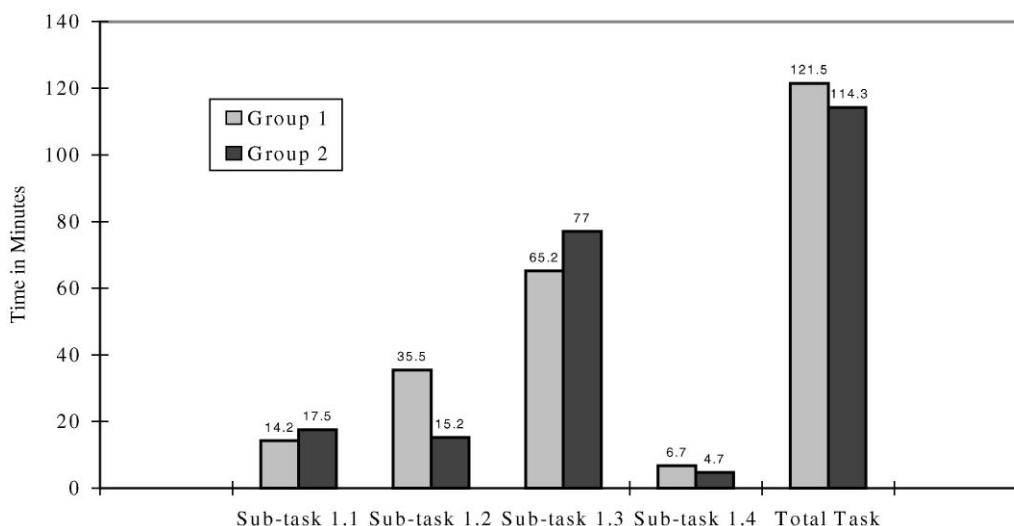


Fig. 6. Time taken to complete sub-tasks for groups IBT and CBT for the routine maintenance task.

center of gravity. The turning point came when the subject who had assumed the leadership role realized that he needed to take control and requested the manual containing the center of gravity calculations. After this point, the leader communicated the procedures to the team, and decisions were made as the team worked towards completing the task. Interestingly, a negative correlation was observed between the completion time for routine maintenance, and the instructors' evaluation of the teams on the use of leadership skills ($r = -0.3305$, $p < 0.049$) and self-evaluation of leadership skills ($r = -0.7029$, $p < 0.0001$).

Sub-task 1.4 (roll out) took the shortest amount of time. There are three possible explanations for this: (1) the teams were performing well as cohesive units at this stage, (2) the teams had learned from previous mistakes made during the rollup (Sub-task 1.2) and, thus, were familiar with the aircraft and the procedures, and (3) it was a relatively short and easy procedure to accomplish. It is hypothesized that all three factors impacted the completion time for Sub-task 1.4. Regardless of the sub-task completion times, it is clear that the training delivery system did not demonstrate any differential effect on the task completion times for the routine maintenance task.

Although no significant differences were observed between the groups on the overall completion times for the non-routine maintenance task, analysis of the results revealed that group CBT required significantly less time to complete Problem 2 (burned out bulb) (Fig. 7). All the teams followed a similar procedure to identify the burned out bulb in the nose landing gear indicator: (1) remove the suspected bulb, (2) insertion of the suspect bulb into a functioning landing gear indicator, and (3) replacement if the bulb did not light up. This procedure was confounded by an iris built into the bulb holders. When the iris was twisted, it would shut out all light from the bulb. In addition, there was a separate test circuit to all the bulbs which permitted a maintenance technician to test a bulb by pushing on the bulb holder. Some of the teams were unaware of the built-in bulb tester, and all the teams were unaware of the iris. Those teams that accidentally twisted the iris closed while replacing the bulb became confused and frustrated because a functioning bulb was failing to work in a functioning landing gear indicator. Because of the above situations, differences in completion times on Problem 2 between the groups could be attributed to some teams accidentally twisting the iris closed. Therefore, the

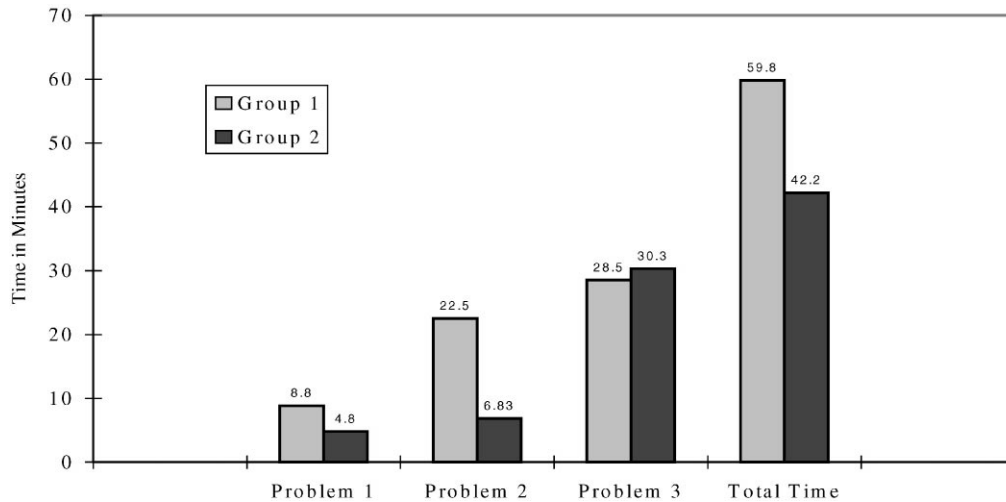


Fig. 7. Time taken by groups IBT and CBT to complete the problems for the non-routine maintenance task.

difference in completion time for Problem 2 could not be attributed to the specific training delivery system.

6. Conclusions

The general goals of this research were to examine the role of the advanced technology, specifically computer-based multimedia presentations, in imparting team skills training to aircraft maintenance technicians and to evaluate the transfer effects of the computer-based training delivery system to the operational environment. As part of the research, a multimedia, computer-based team training software – Aircraft Maintenance Team Training (AMTT) software – was used. The important conclusions drawn are:

1. Team training enhanced the knowledge of individuals on team skills. The type of training delivery system, however, did not have a significant effect on the individual's ability to acquire team skills knowledge.
2. The self and instructors' evaluations on the application of team skills in the operational environment and the performance of the teams on the routine and non-routine main-

tenance tasks were comparable. The transfer of knowledge from the classroom to the hangar floor was the same regardless of the type of training delivery system. For the CBT and IBT teams, the results were unambiguous, indicating clearly that AMTT was as effective in delivering team training instructions as IBT.

3. The results of this research have obvious ramifications for the use of AMTT for team training in the aircraft maintenance environment. In addition to being as effective as existing instructor-based team training methodologies, use of AMTT for team training has these other advantages:

- a. **Standardization:** AMTT provides a systematic and consistent curriculum. Aircraft maintenance instructors at various facilities use their own unique training strategies (straight lectures, classroom discussions, video examples, etc.). In addition, some maintenance instructors who are technically competent may not have sufficient team skills knowledge to train AMTs on teamwork. As a result, when certain teamwork skills are taught, there may be a failure to emphasize certain important team concepts. The AMTT software provides a standardized

and systematic team skills training program which aircraft maintenance instructors (at certified repair stations, airline companies, general aviation stations, and A&P schools) may use to provide team skills training.

- b. Adaptability: most maintenance training is accomplished via on-the-job training or classroom training, both of which are manpower intensive. Traditional training requires careful scheduling of personnel or encumber others in the training process. CBT can be done at convenient times when trainees are available and need only involve the person being trained. In addition, AMTT allows the trainees to learn at their own pace.
- c. Record keeping: The record keeping capabilities of AMTT tracks the student's progress and provides the training supervisor with information concerning the level of understanding being achieved. Information concerning the trainee's knowledge test and perception scores are maintained in a database, and instructors (supervisors) are able to use this information to design remedial training as well as potential future training programs.
- d. Cost effectiveness: team training using AMTT can be cost effective because: (1) it can be delivered on-site thus eliminating travel expenses for the trainer and the trainee. (2) it can minimize down-time by providing training at times that are convenient to the trainee and the company's work schedule. In larger organizations, AMTT can be delivered to many people at multiple sites thus proving to be cost effective.
- e. Use of advanced technology: many facilities, for example A&P Schools and fixed based general aviation facilities, do not have access to larger aircraft. The AMTT software provides team skills training against the backdrop of maintaining a DC-9. Thus the trainees not only acquire knowledge and skills on teamwork but also gained an understanding of the

importance of teamwork in the maintenance of wide-body aircraft.

Acknowledgements

This research was funded by a grant from the Federal Aviation Administration, Office of Aviation Medicine (Program Manager: Jean Watson) through the Galaxy Scientific Corporation to Dr. Anand Gramopadhye. We would like to thank Lockheed Martin Aircraft Center and the Aircraft Maintenance Technology Program at Greenville Technical College for the use of its facilities in conducting this research. We also acknowledge the support of Doyle Arnold, Frank Webb, and Ron Knauer of Greenville Technical College, and Don Cope, Mike Mason, and Hy Small, at Lockheed Martin Aircraft Center.

References

- Chandler, T.N., 1996. System for training aviation regulations (star): development and evaluation. Human Factors in Aviation Maintenance – Phase Six: Progress Report. FAA, Washington, DC.
- Drury, C.G., Prabhu, P., Gramopadhye, A.K., 1990. Training for visual inspection. Proceedings of the 3rd Federal Aviation Administration Meeting on Human Factors in Aviation Maintenance and Inspection: Training Issue. FAA, Atlantic City, NJ.
- Drury, C.G., Gramopadhye, A.K., 1991. Speed and accuracy in aircraft inspection. Work performed under Subcontract No. 8901014-SC-03 to Galaxy Scientific Corporation. FAA, Washington, DC.
- FAA (Federal Aviation Administration) Office of Aviation Medicine. 1991. Human Factors in Aviation Maintenance – Phase One: Progress Report. DOT/FAA/AM-91/16. FAA, Washington, DC.
- FAA (Federal Aviation Administration) Office of Aviation Medicine. 1993. Human Factors in Aviation Maintenance – Phase Two Progress Report. FAA, Washington, DC.
- FAA (Federal Aviation Administration) Office of Aviation Medicine. 1995. Human Factors in Aviation Maintenance – Phase IV: Progress Report. FAA, Washington, DC.
- Glickman, A.S., Zimmer, S.R., Montero, C., Guerette, P.J., Campbell, W.J., Morgan, B.B. Jr., Salas, E., 1987. The evolution of teamwork skills: an empirical assessment with implications for training. Technical Report No. 87-016. Office of Naval Research, Orlando, FL.
- Gordon, S.E., 1994. Systematic Training Program Design: Maximizing Effectiveness and Minimizing Liability. Prentice-Hall, Englewood Cliffs, NJ.

- Gramopadhye, A.K., Kraus, D., Jebaraj, D., Rao, P., 1996. Advanced Technology Applied to Team Training: Aircraft Maintenance Team Training (AMTT) Software. Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting, 1072–1076.
- Hackman, J.R., 1990. A normative model of work team effectiveness. Technical Report No. 2. Yale University, New Haven, CT.
- Johnson, W.B., 1990. Advanced technology training for aviation maintenance. Final Report of the 3rd FAA Meeting on Human Factors Issues in Aircraft Maintenance and Inspection. Atlantic City, FAA, NJ.
- Johnson, W.B., 1997. Human factors training for aviation maintenance personnel. Proceedings of the Human Factors and Ergonomic Society 41st Annual Meeting. Albuquerque, NM.
- Kraus, D.C., 1996. Team Training, Teamwork and Team Performance: Role of Advanced Technology for Team Training in the aircraft Maintenance Environment. Clemson University, Clemson, SC.
- Kraus, D., Gramopadhye, A.K., 1999. Computer-based Team Training: The Aircraft Maintenance Environment Example, Computers and Industrial Engineering, Vol. 36, No. 9, 635–654.
- Kraus, D.C., Gramopadhye, A.K., Blackmon, R.B., 1996. Teams in the aircraft maintenance environment. Proceedings of the 5th Industrial Engineering Research Conference.
- Leshin, C.B., Pollock, J., Reigeluth, C.M., 1992. Instructional Design Strategies and Tactics. Educational Technology Publications, Englewood Cliffs, NJ.
- Layton, C.F., 1992. Emerging technologies for maintenance job aids. 7th Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection. FAA, Atlanta, GA.
- Phillips, E.H., 1994. Focus on accident prevention key to future airlines safety. Aviation Week and Space Technology, 52–53.
- Rankin, B., Allen, J., 1996. Boeing Introduces MEDA: Maintenance Error Detection Aid. Airliner. April–June.
- Reichow, D., 1994. Application of computer-based training for improved maintenance training efficiency. Eighth Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection. FAA, Alexandria, VA.
- Shepherd, W.T., 1992. Meeting objectives. Human factors issues in aircraft maintenance and inspection: Final Report, FAA, Washington, DC, pp. 14–38.
- Shepherd, W., Layton, C.F., Gramopadhye, A.K., 1995. Human factors in aviation maintenance: current FAA research. Proceeding of the 8th International Symposium on Aviation Psychology, FAA, Washington, DC, pp. 466–471.
- Taylor, J., 1990. Facilitation of information exchange among organizational units within industry. Second Federal Aviation Administration Meeting on Human Factors Issues in Aircraft Maintenance and Inspection, FAA, Washington, DC, pp. 69–78.
- Tuckman, B.W., 1965. Developmental sequence in small groups. Psychological Bulletin 63 (6), 384–399.
- Wheelan, S.A., 1994. Group Process: A Developmental Perspective. Allyn & Bacon, Boston, MA.